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Coal dust dispersal around a marine coal terminal (1977–1999), British Columbia: The fate of coal dust in the marine environment

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Abstract

A 1999 assessment of sediments, adjacent to the Roberts Bank coal terminal in Delta, British Columbia, Canada, shows that the concentration of coal particles (reported as non-hydrolysable solids or NHS) has increased substantially since a prior study in 1977. NHS concentrations have doubled from a mean concentration of 1.80% in 1977 to 3.60% in 1999. Overall the dispersal distance of coal has not increased over the 22-year period but rather the abundance of coal in the surface sediment within the dispersal area has increased. Since 1977 the main deposition of coal has occurred in the vicinity of the coal-loading terminals, where concentrations of 10.5% and 11.9% NHS (non-hydrolysable solids = coal) occur.

The settling properties of fresh and oxidized coal particles (<53 μm up to >2.36 mm) were examined in order to better understand the dispersal of coal in marine waters. No change in settling velocity of coal particles occurred with increasing oxidation. However, the proportion of buoyant coal particles decreases with oxidation in all size fractions, reflecting the decrease of coal hydrophobicity with oxidation.

The distribution of coal around the terminals agrees with measured particle settling velocity and current velocity, with coal concentration decreasing rapidly away from the terminal. Coarser sediment fractions contain the highest coal (NHS) concentrations and carbon/nitrogen ration when compared to finer fractions. Coal particles with >2.36 mm diameter (settling velocities ≤10.54 cm/s) settle out close to the terminal (depending on currents), whilst small (<53 μm) and weakly oxidized coal particles travel further and take longer to settle out (settling velocities ≥0.16 cm/s). This results in a wider dispersal of coal particles, and a corresponding decrease in the coal concentration.

Coal distribution would likely affect those benthic flora and fauna, most susceptible to coal dust coverage and possible anoxic conditions that might arise during coal oxidation within very close proximity (0–100 m) to the coal-loading terminal.

Keywords: Coal contamination; Coal environment; Coal settling velocity

1. Introduction

The Roberts Bank coal terminal has been in business for over thirty years and is presently operated by Westshore Terminals Ltd (Fig. 1). Located on Roberts Bank in the municipality of Delta, British Columbia, Canada, it is the first stage in a proposed development of a major bulk-loading port and industrial park, as the major terminals in Burrard Inlet (Vancouver, B.C.) exceed their exporting and development capacities.

However, Roberts Bank is not naturally a deep-sea port and is located in one of the most ecologically

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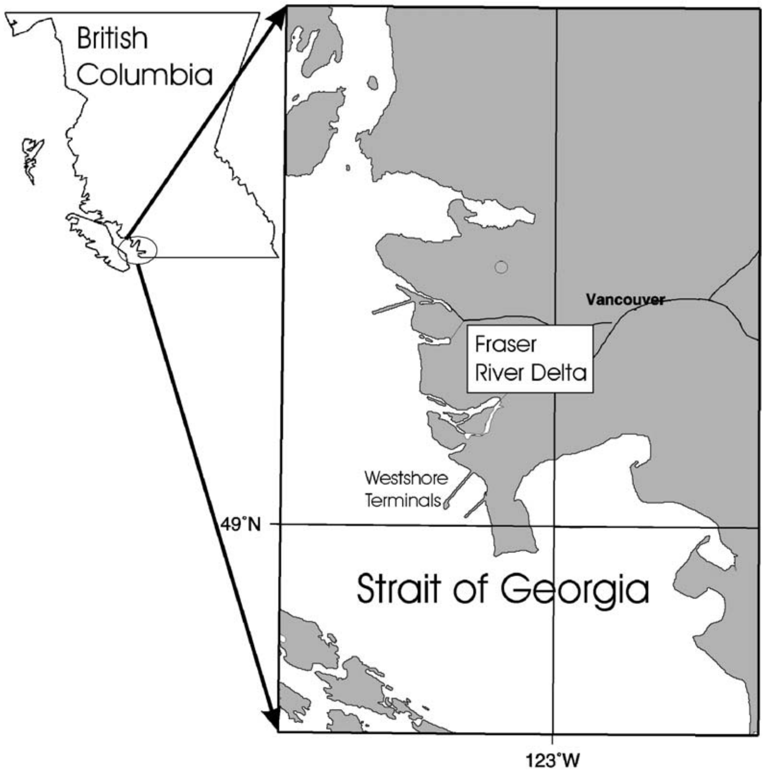

Fig. 1. Location of Westshore Terminals and Fraser River Estuary, British Columbia, Canada.

important estuaries on the west coast of North America. The construction of the coal terminal has had numerous effects on the local ecology, and the release of coal dust has had a detrimental impact on the region.

This paper investigates the coal content of the sediments in the vicinity of the coal loading facility, and reveals significant changes in sediment coal content and distribution in the 23 years since the previous study. An assessment of the settling properties and velocities of the coal particles in the water column were conducted to predict coal particle dispersal around the terminal, and these results are compared with the observed distribution of coal in the sediments adjacent to the coal loading facility. Some of the effects of this coal accumulation on the local ecology are also discussed.

2. History and previous studies

In April 1970, shipments of coal mined in the interior of British Columbia and Alberta began from the Roberts Bank coal terminal located south of the Main Arm of the Fraser River, just south of Vancouver (Fig. 1). The present facility consists of a 96-hectare man-made island situated at the end of a 4.8-km long causeway, serviced by a 20-m deep dredged waterlot and a large ship turning basin located between the terminal and the Tsawwassen Ferry terminal (Fig. 2).

Westshore Terminals handle approximately 30% of the shipping volumes of the British Columbia Lower Mainland. Approximately 90% of this volume is coal that is transported to the facility in unit trains, where the coal is unloaded and stored in large unprotected stockpiles. The coal is subsequently loaded aboard ships ranging in size form 45 000 deadweight tonnes (DWT) to 250 000 DWT for export from two major coal-loading terminals, referred to as pods #1 and 2 (Fig. 2). Coal shipments have increased from 10.6 million metric tonnes in 1980 to a maximum of 23.5 million in 1997. Estimates forecast a continued increase of 4% per annum until 2010 (Fraser River Estuary Management Program (FREMP), 1990a,b). Annual shipments are projected to reach 30 million metric tonnes of coal only with modification of Pod #3, as this terminal is presently being used as a bulk cargo terminal (Deltaport).

In 1975, Westshore Terminals Ltd. applied for a permit under the British Columbia Pollution Control Act, 1967 (Emissions), to discharge “unknown and immeasurable” quantities of coal dust to the air (Pearce and McBride, 1977) as they had previously operated

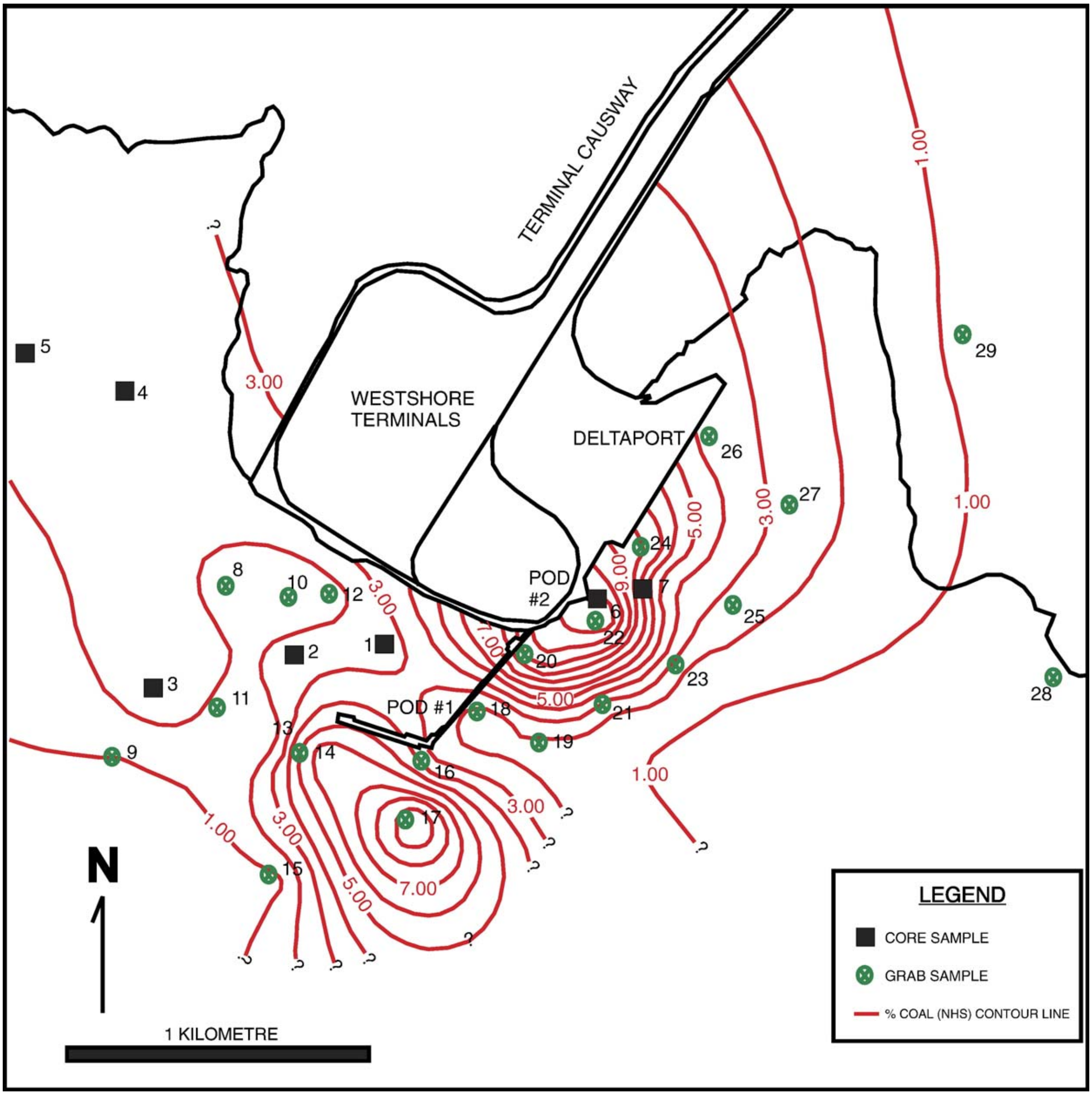

Fig. 2. Sample location and coal dust distribution in surface sediment as measured in weight percent NHS.

without a Pollution Control Branch permit. Local residents as far away as Pt. Roberts, have often complained of the coal dust escaping the terminal (Department of Fisheries and Environment Canada, 1978) from the incoming loaded rail cars, conveyor belts, and returning empty trains during the loading processes. Emissions from open stockpiles also contribute to the coal dust (especially during high wind periods), though it occurs to a lesser degree due to the use of resin binders such as polyvinyl acetate (Pearce and McBride, 1977).

Coal accumulation in bottom sediments, documented by Butler (1972) and Butler and Longbottom (1970) stimulated the Habitat Protection staff of the Fisheries and Marine Service to undertake a limited program in 1975 to study the further accumulation of coal in marine sediments around the terminal, and the possible effect of this coal accumulation on the local ecology. Pearce and McBride conducted the last of these studies in 1977 (Darrel Dejerdin, Vancouver Port Authority, Environmental Services, pers. Comm., 1999) and concluded that the coal content of the sediments adjacent to the Roberts Bank (reported as non-hydrolysable solids) increased only slightly in the five years since Butler's investigation.

3. Study area

Historically, man's encroachment upon, and development of the ecologically important Fraser Estuary/Delta has generally been both ad hoc and unrestricted. This uncoordinated approach to resource use, without regard to, or knowledge of effects on the environment has led to very significant changes in the environment. Since the 1800's, roughly 70% of the estuary's original wetlands have been lost to dyking, dredging, draining, and filling (FREMP, 1997). However, the total area of freshwater and brackish marshes on the outer estuary may have increased in the last century due to the accretion of mudflats on Sturgeon and Roberts Banks (FREMP, 1996).

3.1. Physical environment

Annual deposits on Roberts Bank of approximately 17 million tonnes of sediment are supplied by the Fraser River (FREMP, 1996), the largest river on the west coast of North America (Fig. 1). This sedimentation plays a vital role in the creation of much of the aquatic habitat on Roberts Bank, and is in a dynamic state due to interacting and variable river flows and tides. Constant dredging is necessary to maintain depths of navigable shipping lanes in the vicinity of Westshore Terminals, and recent applications (Westshore Terminals Administrative Department, 1998) have been submitted to dredge approximately 4000 m^3 in the immediate vicinity of Pod #2, (Fig. 2; Dariah Hasselman, FREMP, Project Review Coordinator, pers. comm.).

Roberts Bank comprises approximately 8000 of the total 14,000 hectares of tidal flat associated with the Fraser River Delta. The dominant platform of Roberts Bank is over 6-km wide and slopes gently from the dyked delta lowlands out to a distinct break in slope, approximately 9 m below the lowest normal tide level (Fig. 2). In the vicinity of the Westshore Terminals causeway, the intertidal area exposed between high and low water is approximately 3000-m wide. Tidal channels, current, and wave ripples interrupt the otherwise featureless bank (Luternauer and Murray, 1973; Luternauer, 1974.

3.2. Estuarine ecology

The Fraser River estuary is notable for its biological productivity. This is especially evident between the Roberts Bank Coal Loading Port and the Tsawwassen Ferry Terminal, home to tidal flats, wetlands and eelgrass beds. These habitats form the basis for populations of varied estuarine life forms (in addition to the large numbers of migratory salmon and waterfowl) including the benthos, plankton and fish (Federal Environmental Assessment Review Office, 1979; Fraser River Estuary Management Program, 1989, 1991a, 1991b, 1993, 1994).

The benthos, composed of organisms dwelling on the sea bottom and in sediments are the most greatly affected due to the disturbance of the bottom caused by deposition of coal particles. Anoxic conditions, evident from the presence of hydrogen sulphide, in the sediments receiving very high levels of organic input (including coal), caused by the consumption of oxygen during the degradation (oxidation) of organic matter, would likely have the most detrimental impact on the benthic florae and faunae.

The ecological contribution of bottom microinvertebrates is very significant, as larvae from clams, mussels, barnacles, and crabs drift out to sea and constitute a substantial proportion of the seasonal food for juvenile salmonids and herring. Damage to the benthos therefore has serious implications for both the mature invertebrate populations as well as those creatures that predate upon the benthic larvae.

The Fraser River and its estuary support one of the largest commercial, recreational, and aboriginal salmon fisheries in British Columbia, which includes salmon, surf smelt, eulachon, cutthroat trout, steelhead trout, white sturgeon, mountain whitefish, and Dolly Varden. The annual commercial fishery of Fraser River salmon between 1989 and 1992 was valued of over $115 million (Canadian dollars), with a post-processing wholesale value of over $230 million (Environment Canada and Fisheries and Oceans Canada, 1995). Additionally, sport fishing throughout British Columbia earns about $180 million/year in direct revenues, with Fraser River Chinook and Coho comprising a large percentage of this catch (Environment Canada and Fisheries and Oceans Canada, 1995). Furthermore, seven native bands (Musqueam, Tsawwassen, Semiahmoo, Coquitlam, Katzie, Matsqui, and Langley) participate in the aboriginal food fishery in the Fraser River Estuary.

On Roberts Bank, the Dungeness crab is the only species that is exploited commercially and recreationally, representing approximately 10% of the total catch in British Columbia (Environment Canada and Fisheries and Oceans Canada, 1995). The reported darker coal-coloration of some crabs taken from Roberts Bank is a concern of local fishermen who find the darker crabs more difficult to market.

4. Material and methods

4.1. Sediment and sample collection

A benthic sample of the sediments was collected from each of 29 subtidal sampling stations (Fig. 2). The station locations were established using a differential GPS device and cross-referenced with the Canadian Hydrographic Chart #3492 (Fig. 2) and were chosen at roughly 200 m intervals radiating from the two main coal-loading terminals (pods #1 and 2). Stations 28 and 29 were situated closer to the Tsawwassen ferry terminal to act as 'controls'.

A gravity impact corer was used to collect the first seven samples at high tide on October 22, 1999 and a Shipek© model sediment sampler was used to collect the last 22 samples on November 26, 1999.

Upon retrieval, the uppermost 2–3 cm (approximately 200 g) of the samples were removed and placed in sealed plastic bags while the remainder of the samples were placed in larger bags, or retained in the core tubes. The samples were transported immediately to the laboratory and placed in a freezer to prevent decomposition.

Two coal samples (samples 30 and 31) from the Balmer seam (R_0 ~1.4%) of the Early Cretaceous Mist Mountain Formation (Kootney Group) were used in both the sediment coal content and coal settling property analyses, as these metallurgical coal samples are representative of the majority of coal exported from the Westshore Terminals facility.

4.2. Analytical techniques

4.2.1. Sediment coal content analysis

Determination of the coal content in the 29 sediment samples (each measured in duplicate) was performed using a modified hydrochloric acid hydrolysis method, mimicking the analytical procedure of Pearce and McBride (1977). During this process hydrolysable protein and acid-soluble carbonates are removed by hydrochloric acid hydrolysis with the remaining non-hydrolysable organic matter being removed by hydrogen peroxide oxidation.

Coal is essentially unaffected by the peroxide oxidation and hydrolysis, and its concentration is determined by subsequent gravimetric analysis and ashing. Coal content is reported here as percent total non-hydrolysable solids (NHS), while the organic content is reported as the percent total hydrolysable solids (HS).

The percent NHS is not a measure of the actual coal content of the marine sediments, mainly due to the presence of hydrolysis-resistant organic material such as wood, charcoal, and bark. Post-hydrolysis combustion of such materials would provide an overestimate of the actual coal content by resulting in an elevated NHS value. Despite this source of error, investigations have shown that NHS values do provide an indication of the coal content in marine sediments (Pearce and McBride, 1977).

Two coal samples from the Balmer seam were also analyzed to allow an estimate of coal lost during the digestion process as well as determining the ash content.

4.2.2. Sediment particle size analysis

Sediment particle size analyses were performed on the seven core samples using the wet sieve method described by Morgans (1956) to minimize the loss of particles and reduction in their grain size. The sediments were sieved into five different size fractions and then dried at 50 °C for 3 h prior to being weighed. Cumulative weight percents were plotted against grain size values to obtain an estimate of the grain size distribution in the vicinity of Westshore Terminals, as well as the degree of sediment sorting. Individual sieve fractions were examined with a microscope to determine an estimate of the fractions in which most of the coal grains occur.

4.2.3. Sediment organic/inorganic carbon and nitrogen analysis

Upon completion of the sediment particle analysis, samples were ground to less than 53 μm using a mortar mill. The organic carbon content for the various sediment size fractions was determined from the difference between total carbon content and inorganic carbon (IOC) content, with IOC content being determined by coulometric analysis.

Sediment total organic carbon (TOC) and nitrogen content for the sediment size fractions were determined using an instantaneous oxidation of the sample by 'flash combustion' and subsequent chromatographic analysis.

4.2.4. Coal settling properties analysis

A series of settling velocity experiments were performed to determine the settling characteristics of coal under various conditions in an attempt to explain the distribution of coal in the sediments surrounding Westshore Terminals. The effects of moisture and various degrees of oxidation on the hydrophobicity of the coal particles were investigated to determine the conditions under which various size fractions would float or sink, as well as to determine their settling velocities.

Coal samples from the Mist Mountain Formation were crushed using a mortar and pestle, dry sieved to the desired size fractions, and placed in sealed plastic containers. Five, 1-g samples of the smallest coal size fraction (<53 μm) were gently placed on the surface of 200 ml of seawater in open jars, and left exposed to the atmosphere for a month without agitation.

The remaining samples of the larger size fractions were divided into four subsamples. One group remained in the sealed plastic containers; the second group was placed on open aluminum foil trays at approximately 25 °C; the third group was placed in open beakers an oven at 50 °C; and the fourth group was placed in open beakers in the oven at 100 °C.

Settling velocities were determined in a 1000-ml test tube filled with 25 °C seawater by dropping individual coal particles from 8 cm above the water surface (to partially overcome surface tension), and the settling time was recorded for individual particles to settle 30 cm in the test tube. Ten trials were run for each size fraction, and an average of the trials was calculated. The number of buoyant coal particles was also recorded, as well as whether agitation was necessary to initiate particle settling. Agitation of the samples involved gently pushing the samples below the water surface with a glass rod; their displacement being factored into the settling times.

The settling velocities of the thirteen different coal size fractions of the first group of 'fresh' (least oxidized) coal samples were measured immediately, while the other three groups were allowed to oxidize for a week at temperatures of 25, 50, and 100 °C. The '100 °C' group of coal particles was returned to the oven for further oxidation and their settling properties were measured on a weekly basis for the following two weeks. Oxidation was confirmed by measuring the loss of caking ability of the coal. Because of the fine particle size, petrographic observations of the samples by light microscopy was not possible.

The densities of the coal samples (larger than 2.36 mm) were measured for the fresh, saturated, and oxidized (25, 50, and 100 °C) groups by weighing the samples in air and in toluene. Specific gravities were determined from the particles' displacement in toluene.

5. Results

5.1. Sediment coal content

The coal and organic content of the sediments, expressed as the percentage of non-hydrolyzable solids and hydrolysable solids respectively, are shown in Table 1.

Based on the sediment NHS content, the subtidal coal distribution in the area around the coal terminal is shown in Fig. 2. The area of greatest accumulation (>11%) is located directly southeast of the Pod #2 coal-loading terminal. This region of high concentration is limited to within a hundred metre radius of the loading facility, and the coal concentration diminishes rapidly to less than 1% within 700 to a 1000 m. A second region of elevated coal dust concentration (>10%) is found approximately 200 m directly south of the Pod #1 coal-loading terminal. Samples were not taken closer to Pod #1 (between stations 14 and 16) because a large coal transport ship was moored at the terminal on both sample collection dates. This region around Pod #1 is

Table 1
Sample location with average total organic carbon content and average coal content (NHS)

Sample station	Average OM content (%)	Average coal content (%)	Sample station	Average OM content (%)	Average coal content (%)
1	17.98	2.74	16	18.62	3.02
2	12.71	2.66	17	31.47	10.47
3	14.46	2.97	18	18.92	1.20
4	14.47	2.52	19	15.45	1.61
5	15.61	2.31	20	14.02	9.90
6	15.17	10.85	21	19.60	2.14
7	22.92	4.22	22	16.12	11.90
8	23.95	1.74	23	16.48	1.95
9	18.28	0.91	24	23.10	7.80
10	17.01	1.62	25	18.26	2.48
11	15.79	1.52	26	24.26	3.29
12	20.74	1.82	27	31.70	2.58
13	14.86	1.04	28 (control)	14.02	0.77
14	14.02	6.72	29 (control)	13.71	0.65
15	13.06	0.92	30 (coal)	0.12	94.89
			31 (coal)	0.77	93.41

also characterized by a high NHS concentration gradient, dropping to levels less than 1% within 500 to 1000 m. An area of moderate accumulation (1–3%) completely surrounds the coal terminal and extends outward for at least 1000 m to the north (limit of sampling), west, and east, and 800 m towards the south. Contouring of Fig. 2 south of stations 15 and 16 is based on limited data. Subtidal control samples collected at stations 28 and 29 (near the Tsawwassen ferry terminal and causeway) contained low (<0.8%) NHS concentrations.

The coal content in the sediments decreased significantly with distance from the terminal (Fig. 3).

Concentrations of hydrolysable matter, assumed to represent organic matter (OM) content, consistently exceeded the non-hydrolysable (coal) content in the sediments in each of the twenty-nine stations sampled. OM was found to compose at least 12% (by weight) of the surface sediment content on Roberts Bank, with a maximum of 31 OM at station 17 (Table 1).

The two Mist Mountain coal samples have an average of 0.44% HS. However, this apparent hydrolysable solid content most likely represents the irremovable coal residue in the test tubes upon completion of the digestion process. The coal samples were analyzed to contain an average of 94.15% NHS, with the decreased mass likely representing the ash content of the coal.

5.2. Sediment particle size

Results from the physical analysis of the sediment samples from the core samples are presented in Figs. 4–6. Subtidal grain sizes range between silt and clay to medium grained sand (<53 to >355 μm). The sediments to the north and northwest of the terminal are primarily silt and fine sand (<53 to 250 μm), while the area to the south and east is dominated by fine to medium sand (125 to 500 μm). The nearshore area adjacent to the coal terminal in the lee of the Pod #1 terminal (Core #1) is dominated by fine sediments in the silt and clay range (<63 μm).

Quartz grains dominate the sand, though a high abundance of lithic grains, shell fragments and mica also occur. Large coal fragments (up to 2 cm in diameter) occur in several of the core and grab samples, and are especially abundant in sample locations 6, 17, 20, and 22. The sediments have a moderate to poor degree of sorting and the larger grains are predominantly subangular with a moderate degree of sphericity. Both the degree of angularity and the composition of these sediments are indicative of poor to moderate chemical and physical maturity.

5.3. Sediment organic/inorganic carbon and nitrogen content

Results from the analysis of the total organic carbon (TOC) indicate that the TOC is highest in the coarser sediment size fractions (>250 μm), with a maximum of 16.8% in Core #6 (Fig. 4). TOC values in the smaller size fractions are generally less than 2%, and the lowest values occur in the 150-μm size fraction.

The inorganic carbon (IOC) values are generally less than 0.7%, with a maximum value of 1.2% occurring in the coarsest fraction (355 to 500 μm) in cores 1 and 7.

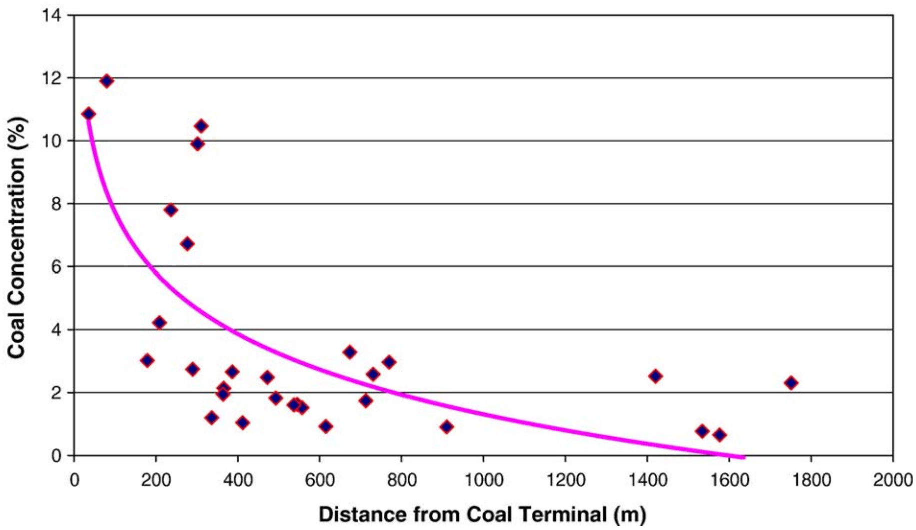

Fig. 3. Coal concentration (wt.%) with distance from the coal terminal.

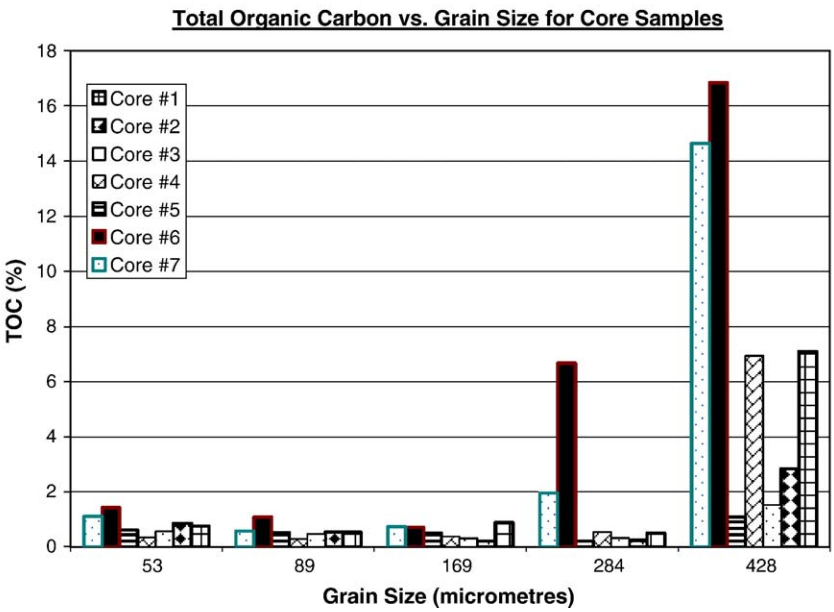

Fig. 4. Total organic carbon content vs. particle size distribution of samples for cores collected across study area (core locations are shown in Fig. 2).

Minimum values of IOC content are found to coincide with a grain size of approximately 200 µm, albeit a poor correlation.

Trends in the sediment nitrogen concentrations are found to generally conform to those of the TOC concentrations, although the nitrogen concentrations are considerably less (Fig. 5). Maximum nitrogen concentrations reached 0.34% in the largest size fraction (355 to 500 µm), while the nitrogen content in the majority of the other size fractions rarely exceed 0.10%. Minimum concentrations of approximately 0.03% nitrogen occur near the 200 µm size fraction.

A ratio between the carbon and nitrogen was plotted against the various core sample grain size fractions to determine whether or not the carbon being measured was from a terrestrial or marine source. Terrestrial carbon sources are known to generally have a higher C/N ratio than their marine counterparts (Mayer, 1994).

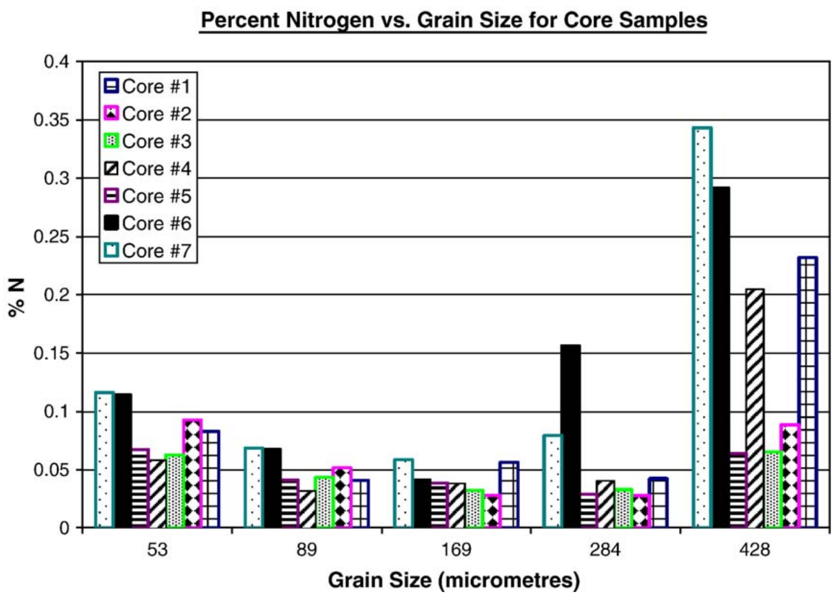

Fig. 5. Particle size distribution of samples vs. the total nitrogen content for cores collected across study area (core locations are shown in Fig. 2).

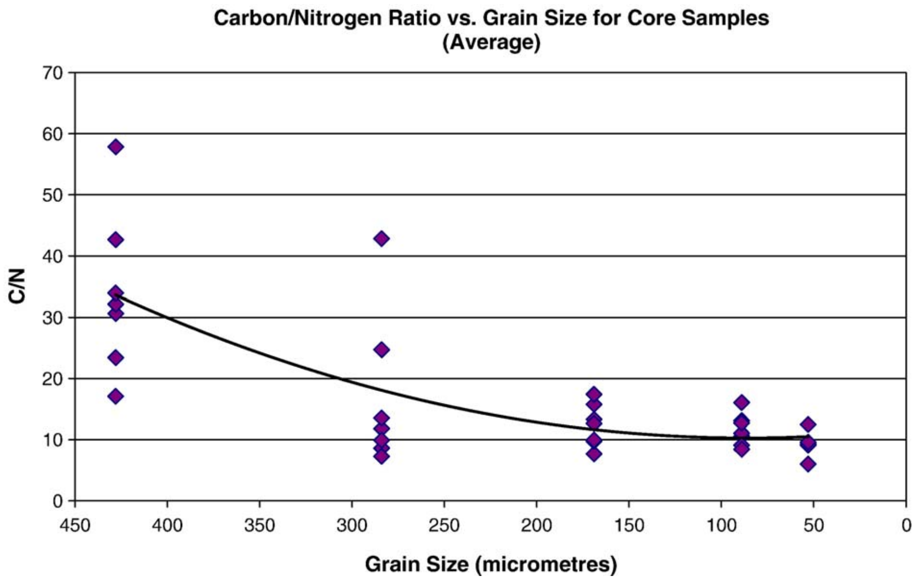

Fig. 6. Carbon to nitrogen ratio vs. grain size.

The highest C/N values occurred in the larger size fractions, and the C/N ratios generally decrease with decreasing particle size (Fig. 6). Cores 6 and 7 have the greatest C/N ratios, with a maximum value of approximately 68 for the 355 to 500 μm size fraction of Core 6. These elevated C/N values generally coincide with the maximum TOC and nitrogen values in the larger size fractions (Figs. 4 and 5), while the lowest C/N values have an approximate correlation with the minimum TOC and nitrogen values of cores 3 and 5 in the smaller size fractions. Cores 1, 2, and 4 lacked correlation between the TOC, nitrogen, and C/N values, although the same general trend can be observed.

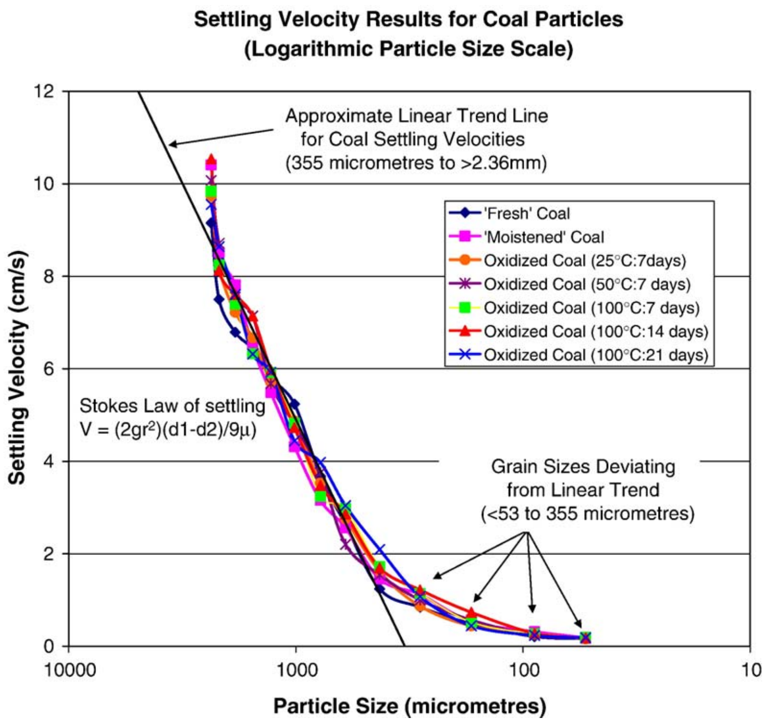

Fig. 7. Variation in coal particle settling velocity with particle size and degree of oxidation. For most particle sizes settling rates follow Stoke's Law.

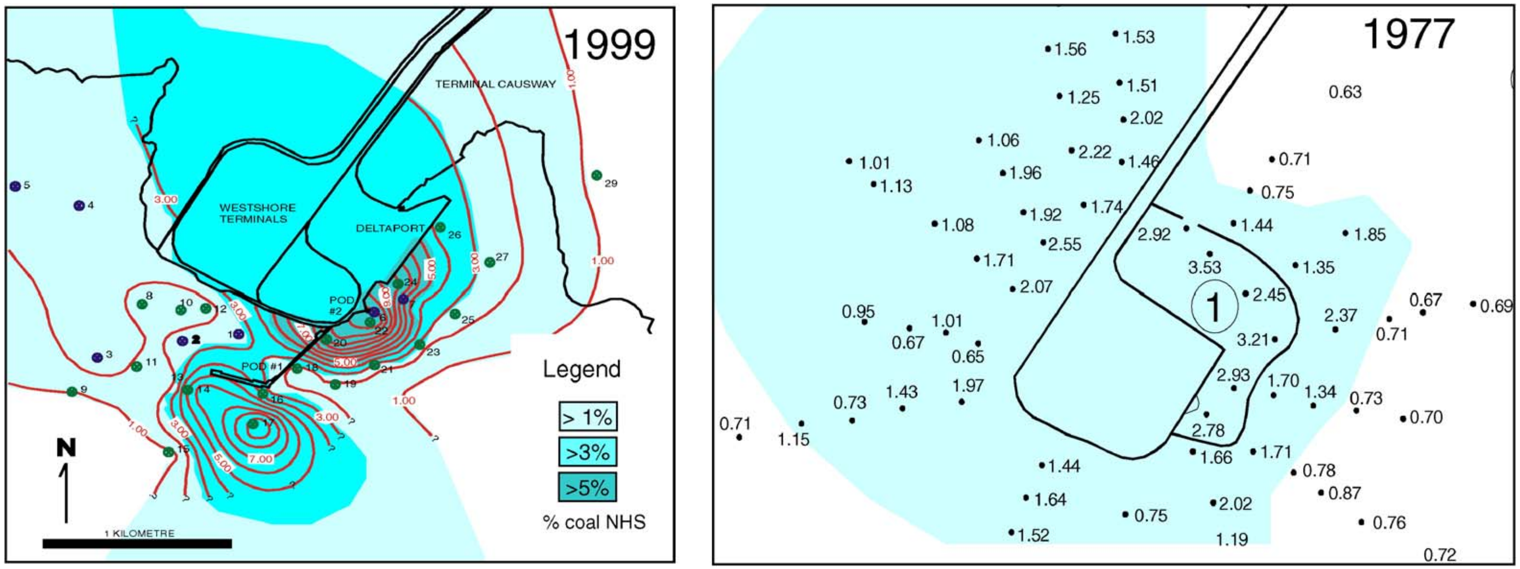

Fig. 8. Comparison of coal distribution (NHS) in 1977 and 1999 in the vicinity of the Terminal. Scale on each map is approximately the same. The aerial extent of the coal has changed little between 1977 and 1999 however the abundance of coal is markedly higher in surface sediments in 1999. The scale for both maps is the same.

5.4. Coal settling properties

The settling velocity results are presented in Figs. 7 and 8. The vast majority (>99%) of the five smallest samples (<53 μm) placed in open jars of quiescent seawater remained on the surface after a month; agglomerating into balls up to 1 cm in diameter. This agglomeration is likely the result of a weak electrostatic attraction between the fine coal particles as they also aggregate in a dry container, disintegrating only when shaken vigorously. The rest of the coal dust remained on the surface as a thin film, attesting to the hydrophobicity of the coal. The resistance to settling of the coal particles could also be due to surface tension, although one would expect this effect to be overcome when the particles were temporarily immersed in the water during vigorous shaking of the jars. Larger particles that did not settle, aggregated at the surface, even when initially separated by up to 5 cm. This attraction might be due to electrostatic forces and mutual repulsion from the water (hydrophobicity). The particles remained bound even after agitation and would settle at a greater velocity due to their combined radii.

The settling velocities of the different coal size fractions did not change significantly with oxidation, as illustrated by the similar trends in settling velocities in Fig. 7. Nonetheless, the settling velocities for the larger grain sizes (1.7 to >2.36 mm) increased slightly when the samples were moistened and exposed to various degrees of oxidation. The settling velocity for coal grains larger than 2.36 mm increased from a minimum of 9.15 cm/s ('fresh' coal) to 10.54 cm/s (100 °C: 14 days). However, exposure of the coal to 25, 50, and 100 °C oxidation conditions over the course of the experiment did not result in a consistent increase in settling velocity for the remaining grain size fractions.

As predicted by Stokes Law, the settling velocities decreased exponentially with decreasing particle size (diameter) for the majority of the grain sizes. The approximate linear trend line illustrated in Fig. 7 when the particle sizes are plotted on a logarithmic scale demonstrates this relationship. The smaller grain sizes (<53 to 355 μm) deviated from this trend, with a reduced rate of settling velocity increase with increasing particle size.

Although the settling velocities of the coal did not change significantly with oxidation, there was a consistent decrease in the size fraction where agitation was necessary. The least oxidized coal samples (based on time of exposure and confirmed by loss of caking ability) were found to have a greater proportion of particles that would float than those oxidized more thoroughly. Agitation was generally necessary for grain sizes smaller than 500 μm.

The specific gravities of the coal particles did not change dramatically under the various exposure conditions averaging 1.39±0.05 for all of the subgroups. However, the specific gravity did vary by as much as 0.10 within each group, attesting to the heterogeneity of the small coal samples.

6. Discussion and conclusion

An assessment of the benthic sediments adjacent to the Westshore Terminals coal terminal on Roberts Bank has shown that the concentrations of coal in the sediments (reported as NHS) has increased substantially since it was last investigated in 1977, having doubled from a concentration of 1.8% in 1975 to a mean concentration of 3.60% in 1999. NHS concentrations range from 0.65% in the 'background' samples 1.5 km away up to 11.90% in the immediate vicinity of the coal loading terminals. Since 1977 the main deposition of coal appears to have occurred in the vicinity of Pods #1 and 2 coal loading terminals, although limited samples were taken on the north side of the coal terminal causeway (Fig. 8). Coal concentrations in the sediments generally decrease rapidly with increasing distance from the terminal. Overall, the dispersal distance of coal has not increased over the 22-year period but rather the abundance of coal in the surface sediment within the dispersal area has increased.

The settling velocities of coal particles ranging from <53 to >2.36 mm did not change significantly with increased saturation and oxidation, although the saturated samples and those that were oxidized did settle faster in the largest size fraction (>2.36 mm). However, the proportion of buoyant coal particles decreased with increasing exposure to oxygen and temperature of heating throughout the range of coal size fractions examined, supposedly reflecting the decrease of coal hydrophobicity with increased oxidation.

Settling velocities for the coal particles in sea water analyzed in this experiment range from 0.16 to 10.54 cm/s for the <53 μm and >2.36 mm size fractions, respectively. These size fractions represent the majority of coal that could escape in the local winds (via deflation and saltation) during the loading processes and from the stockpiles themselves. Local winds average between 10–15 km/h throughout the year and attain speeds in excess of 60 km/h, especially during the winter months (Environment Canada, 1963–1990).

The regions around the coal terminal with the highest coal concentrations average depths between 5–20 m (Fig. 2). According to this experiment, the largest size fraction (>2.36 mm) would take between 47 s and 3 min to settle 5 and 20 m, respectively. Assuming that the smallest fraction (<53 μm) would settle, it would take coal particles of this size fraction between 52 min and 21 h to settle the same depths. However, both of these calculations assume that the water column lacks any vertical or horizontal currents. Such conditions are rare at Roberts Bank, and would only occur at slack tide on an extremely calm day. The action of any currents in the water column would have drastic repercussions on the settling velocities of the coal particles, especially for the smaller size fractions. ` On Roberts Bank, normal maximum tidal currents alone can reach 0.051–0.76 m/s near Pod #1 (Canadian Hydrographic Service). In such currents the coal particles larger than 2.36 mm could travel laterally up to approximately 60 m to settle 5 m through the water column, and travel 230 m to settle 20 m. In the same currents, the smallest size fraction could travel between 4 and 96 km laterally to settle to the same depths (although it is highly unlikely that maximum tidal currents could be sustained for the 21 h necessary for 96 km of dispersal). Upwelling currents and turbulence would also contribute to the residence time of the coal particles in the water column. Furthermore, these calculations assume that the particles would settle in the first place, though the waves and currents would undoubtedly agitate the coal particles to a degree and initiate settling.

The hydrophobicity of the coal particles would result in particles staying afloat longer than assumed in the above calculations. During the sampling a thin layer of small coal particles floating on calm water approximately 200 m east of Pod #2 was observed. This film of fine coal particles was observed when there was no coal loading activities in progress, and no ship was docked.

The distribution of coal around Westshore Terminals is in agreement with the data from the analysis of the coal settling properties. The sediments that contain the highest coal concentrations are in the coarser size fractions in close proximity to the coal loading facility. The experiments studying the settling velocities of the coal particles indicate that the larger coal particles (with settling velocities of up to 10.54 cm/s) settle out within the first few hundred metres of the terminal (depending on the currents). The degree of coal oxidation would dictate which coal size fraction would readily settle, with the increasingly oxidized particles tending to settle due to their decreased hydrophobicity. The smaller particles (as well as those oxidized to a lesser degree) would float longer and take longer to settle (with minimum velocities of 0.16 cm/s) through the water column, resulting in an increased dispersal of the coal, and coincident decrease in the sediment coal content. These low concentrations would be difficult to detect using the hydrolysis method of this study.

Benthic flora and fauna, which are most susceptible to coal dust coverage and possible anoxic conditions that might arise due to the oxidation of the coal, would likely only be affected on sediments within very close proximity (0–300 m) to the coal loading terminals at pods #1 and 2. Creatures dwelling further away would unlikely experience coal concentrations sufficient to blanket the bottom (thereby decreasing insulation) and give rise to anoxic conditions in the upper sediments. Furthermore, in all of the sediments sampled in this study, the hydrolysable organic matter content of the sediments ranged between one-and-a-half to 20 times the coal content (NHS) of the sediments. If anoxic conditions were to arise, they would likely be the result of the natural organic detritus rather than the coal content. Inspection of the sediments around Westshore Terminals failed to reveal any evidence of anoxic conditions in the upper sediments. If anoxic conditions did prevail, the sediments (at a variable depth below the sediment–water interface, depending on the degree of oxidation) would be expected to have a dark (black) coloration and pungent aroma. Such characteristics would reflect a reducing environment in which bacterial degradation of the organic matter (as well as the activities of detritivores) was inhibited by a lack of oxygen.

The benthic creatures dwelling in the sediments adjacent to the coal terminal would more likely be adversely affected by the alteration of their habitat through changes in the physical nature of the substrate such as size, weight, particle shape, porosity, permeability, and stability of the sediments (Pearce and McBride, 1977) due to the dredging operations in the area.

Though this report does not directly address the amount of suspended solid levels (i.e. coal) in the waters around Westshore Terminals, Shelton (1971) documented the effects of dumping annually 6.2 million metric tonnes of fine coal, fly ash and other colliery wastes off the north coast of England. Investigations demonstrated that the growth of periphytic (attached) algae was inhibited by the reduction of light penetration from increased levels of suspended solid load, adversely affecting the fauna associated with the attached algae. While the volume of coal dust settling on Roberts Bank is undoubtedly much less than that documented by Shelton (1971), the study does indicate the effects of suspended coal levels may have on marine flora and fauna.

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